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A COMPARISON OF ATMOSPHERIC TRANSPORT CONSIDERATIONS IN EASTERN AND WESTERN OIL SHALE OPERATIONS

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Abstract

Atmospheric transport represents one of the critically important pathways for the distribution of pollutants from any oil shale operation. Our experience in studying eastern and western shale resources and operation suggest many common features regarding the atmospheric domain, but also many significant differences. Any issue of atmospheric transport and dispersion can be broken down into major elements

- Source factors include the spatial and temporal distribution of pollutant sources as well as their chemical and physical characteristics. The distribution and character of the two resources leads to different plant siting strategies and processing options in the east and west.

- Boundary conditions include the character of the underlying surface as a lower boundary and the large scale meteorological circulations as an "upper" boundary. The lower boundary variabilities present us with enormous challenges including the effect of terrain and land use in creating locally driven wind circulations and their attendant turbulence fields. The ambient meteorology serves to modulate these effects through clouds and moisture which influence radiative cooling of the ground and through wind and temperature fields which introduce competing forcing

- Meteorological structure is the resulting wind, temperature, moisture, and turbulence environment in the volume of air occupied by emitted material in an atmosphere subjected to the boundary conditions described above

For purposes of planning an industry, we want to be able to reliably model the atmospheric structure on a variety of time and space scales and the subsequent distribution of pollutants. This paper will discuss differences in modeling concepts and results in the separate environments of eastern and western oil shale resources

INTRODUCTION

The development of an energy resource like oil shale depends predominantly on economic factors although in the present setting within the U. S., environmental constraints represent a major factor in the feasibility of extracting the resource, the siting of extracting and processing operations and the design of facilities and emissions controls. One environmental factor of great interest is the release of pollutant emissions to the atmosphere and their subsequent transport, transformation, and deposition. In the U. S., there are two major resource regions for oil shale that differ dramatically in their composition, distribution, areal extent and atmospheric environment into which emissions would be injected. These differences suggest that the air quality considerations would be quite different for the two areas. In this paper, we will consider differences in three factors related to atmospheric transport. These are:

1. Source factors. Differences in the distribution and richness of the resource lead to different methods of mining and processing which will be reflected in the atmospheric emissions. Related to this are differences in the mineralogy of the host rock which will produce different bi-products during processing.

2. Air chemistry effects depend on the chemical and physical composition of the emissions, the background of precursor reactants that may be present due to natural emissions or other industrial effluents, and the basic atmospheric environment influencing the chemistry such as ultra violet radiation and moisture.

3. Atmospheric transport is a critical element in the environmental effect of an individual facility or a whole industry since it determines the location and extent of the airborne impact. The "footprint" of effects from transported and deposited emissions is not reliably estimated from the routine meteorological observation networks since the spacing and timing of the observations is inadequate to describe important regional and local circulation patterns. Instead, we should view the transport wind fields as circulations driven by the large scale pressure gradients (resulting from migratory "weather map" scale circulations) and local thermal contrast (land-water, surface cooling on sloped surfaces etc.) and subsequently modulated by the shape and texture of the lower boundary (hills, mountains, ridge-valley complexes, basins, vegetative and microtopographic roughness).

Many distinctions between the eastern and western resource areas enter the picture here. In terms of synoptic patterns the western intermountain area is more susceptible to stationary features and multi-day periods of very weak ventilation. The dry atmosphere permits vigorous surface radiative cooling at night and the local terrain converts the large diurnal temperature cycle into a multi-scalar mosaic of local circulations that tend to reverse from day to night. The eastern resource areas are within and predominantly upwind of areas that are already heavily burdened with industrial and energy emissions. The wind fields are more influenced by the migratory circulation patterns although there are areas of locally generated wind fields and, most certainly, the wind fields that may be drive by the outer boundary condition of the "weather map" pattern will be significantly modulated by local ridge-valley patterns.

SOURCE FACTORS

The source effects encountered in modeling atmospheric transport and transformation are: location (including especially height above ground), size, and duration, thermal content and vertical velocity, physical properties (e.g. particle size distribution) and chemical composition. Many source factors are properties of the particular plant design and not necessarily characteristic of eastern or western shales. However, differences in the resource will lead to differences in the choice of mining and processing so we might expect source factors to differ between the two regions. Figure 1 depicts the relatively compact western oil shale resource areas of Colorado-Wyoming-Utah and the widely distributed eastern shale extending from the Great Lakes southwestward to Oklahoma. Although the eastern shale underlies an enormous area, it is likely to be economically feasible to extract only in outcrops, some of which are indicated in Fig. 1. Peterson (1986) makes an excellent point that the character of the product and waste streams depend on the raw material and its host matrix, conditions of the process, and finally emissions controls. It's really premature to attempt a guess at the chemical composition of atmospheric emissions without knowing the choice of retorting, pre-, and post-processing conditions (atmosphere, temperature, rate of heating, etc.) However we can speculate on what type processes might be selected to effectively exploit the

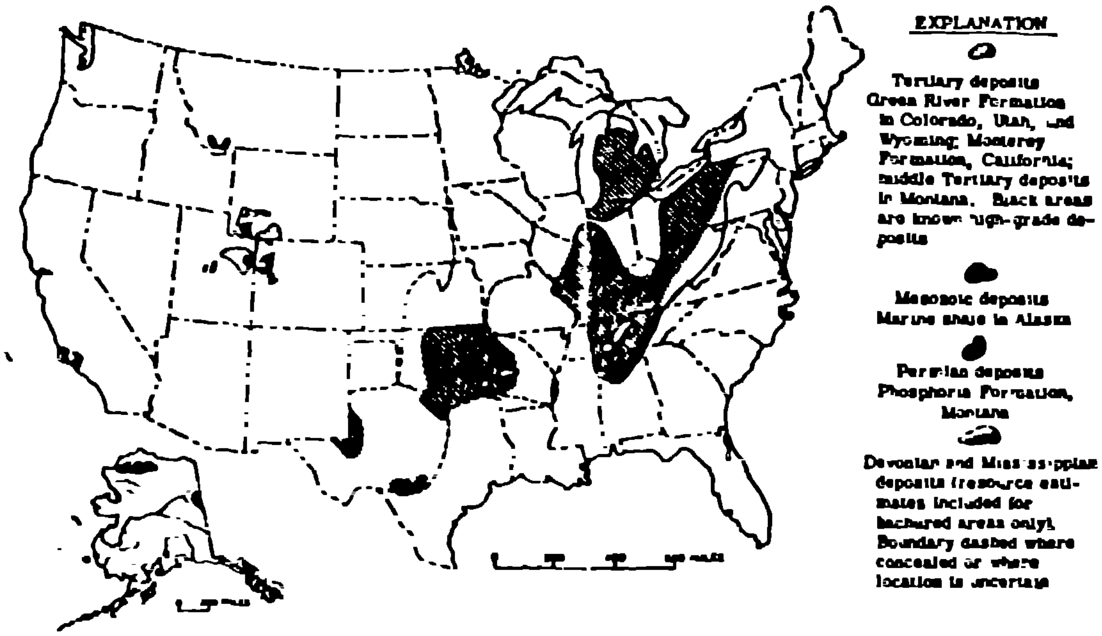

Figure 1. Principal reported oil shale deposits of the U.S.

resources. The thickness of the richest part of the Piceance Basin and Uinta Basin shales invite in situ retorting and underground mines while the shallower deposits of eastern shales will probably be surface-mined. These lead to quite different source configurations. The blasting and hauling operations in an open pit mine would inject materials into the atmosphere that would not be amenable to emission control and would probably be in the form of fine particulate matter. Underground mines would offer the opportunity to clean the emissions resulting from air circulation. Similarly, in situ retorts would be vented at specific locations and air emissions can be controlled there. Above ground retorting would be subject to the same conditions in the eastern and western resource areas. However, similar operations of hauling and handling may lead to more fugitive dust emissions in the arid western locations. Once airborne, these are difficult to control so the best tactic is to prevent fugitive emissions by such steps as spraying water on the roads and shale to be handled.

METEOROLOGY AND TRANSPORT FACTORS

The respective climatologies of the intermountain western oil shale area and the eastern shale regions are dramatically different due to

- their geographic locations on the continent and position with respect to the major mountain barriers,
- the source regions of moist air and subsequent drying processes due to lifting of air over mountain barriers, and
- altitude above sea-level.

The result is that the western shales lie in a high altitude semi-arid regions while the eastern shales are located at lower altitude in the temperate mid-western U. S. with about 40 inches of precipitation per year and considerable cloudiness.

Hoard and Lee (1986) performed a weather map classification to find the most frequent large scale patterns of winds and pressure preparatory to assessing the effect of large scale circulation on the low level transport wind fields in the Colorado-Utah region. Fig. 2 is a multi-panel series of the most common patterns. Similar map classification have been performed for the eastern U. S. with similar results (Lund, 1963). The weather map scale patterns form the boundary conditions for regional and small scale circulations that are produced or modified by local thermal and topographic structure. Some large scale patterns wipe out the smaller scale driving forces by altering cooling rates or simply dominating the momentum transfer while other maps (e.g. light winds, clear skies) permit a maximum local influence.

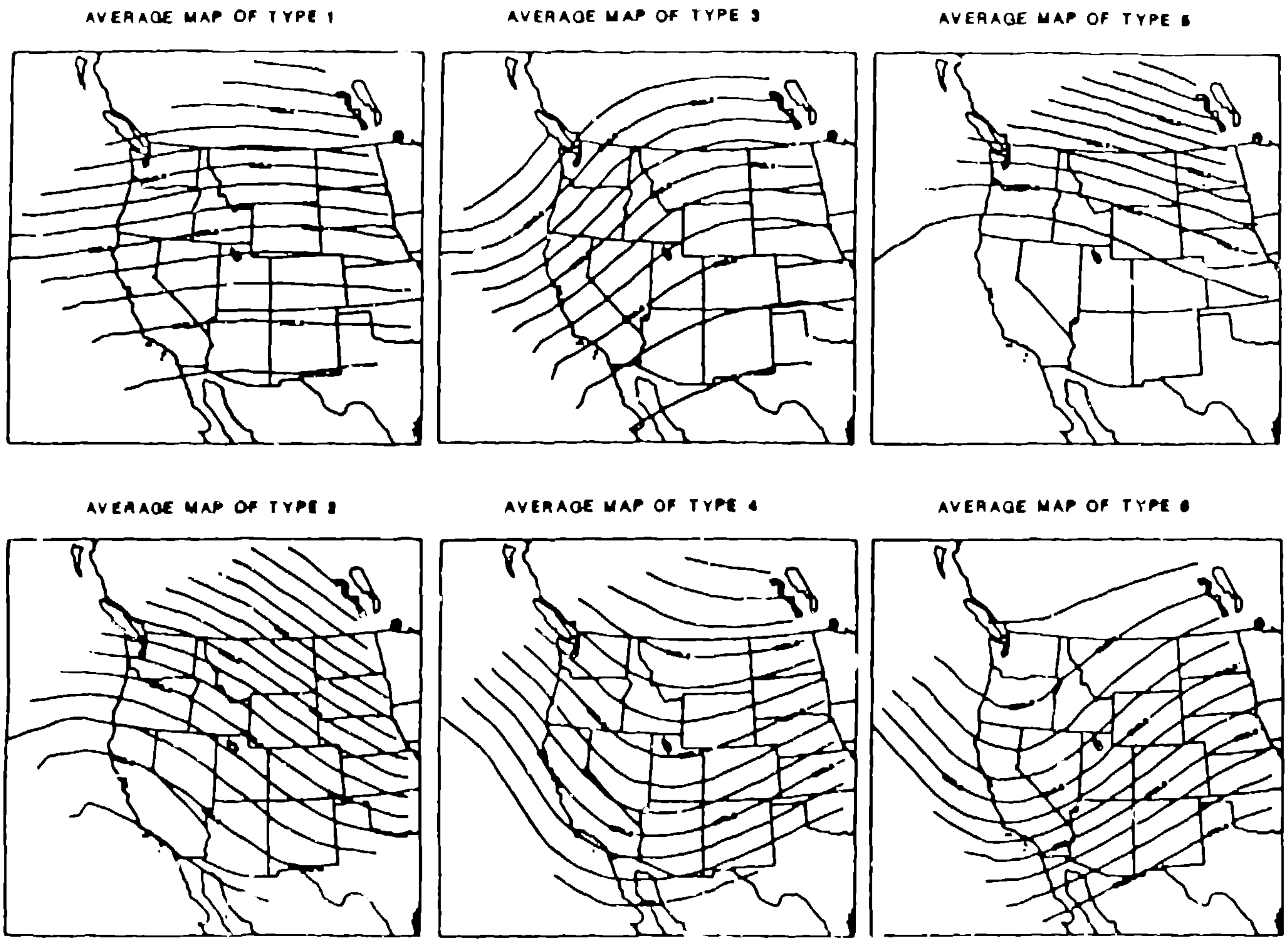

Figure 2. Common circulation patterns over western U.S. The patterns represent an altitude level characteristic of the highest terrain.

Regional Scale Transport

The locations of the western and eastern shale resource areas relative to major North American topographic features give rise to important regional scale circulations that may be superimposed on the synoptic scale patterns and significantly influence the transport paths of atmospheric emissions. The development of understanding of these circulations is at an early stage and we have only a few modeling and empirical studies upon which to base our knowledge. We are becoming convinced, however, that regional scale circulations must be considered in order to reach the proper conclusions on facility siting and development strategies.

The major Rocky Mountain upland of Colorado, Utah, and Wyoming is one of only a few areas in the world with enough height and areal coverage to produce a diurnal plateau circulation with inflow during the day and outflow at night over a region on the order of 1000 km in diameter. Fig. 3 from Barr (1986) depicts the general properties of the flow reversal. It is a weak circulation with wind speeds of only a few meters per second and can therefore be swamped by vigorous winds encountered in the passage of storms and fronts during the winter half of the year. It is driven by a combination of radiative balance (solar and outgoing infrared) and latent heat cycle associated with thunderstorms over the high ground. Hence, the plateau circulation should exert its greatest influence during summer. That influence can include a semi-persistent "sloshing" of polluted air about the basins of the intermountain area. The ROMPEX project (Reiter et al, 1987) describes additional experimental evidence compiled on the properties of the plateau circulation.

The eastern shale regions occupy an area of transition from the eastern great plains to the western slopes of the Appalachian mountains. The mountains are both lower and cover less area than the Rockies, but represent a quasi-linear northeast to southwest

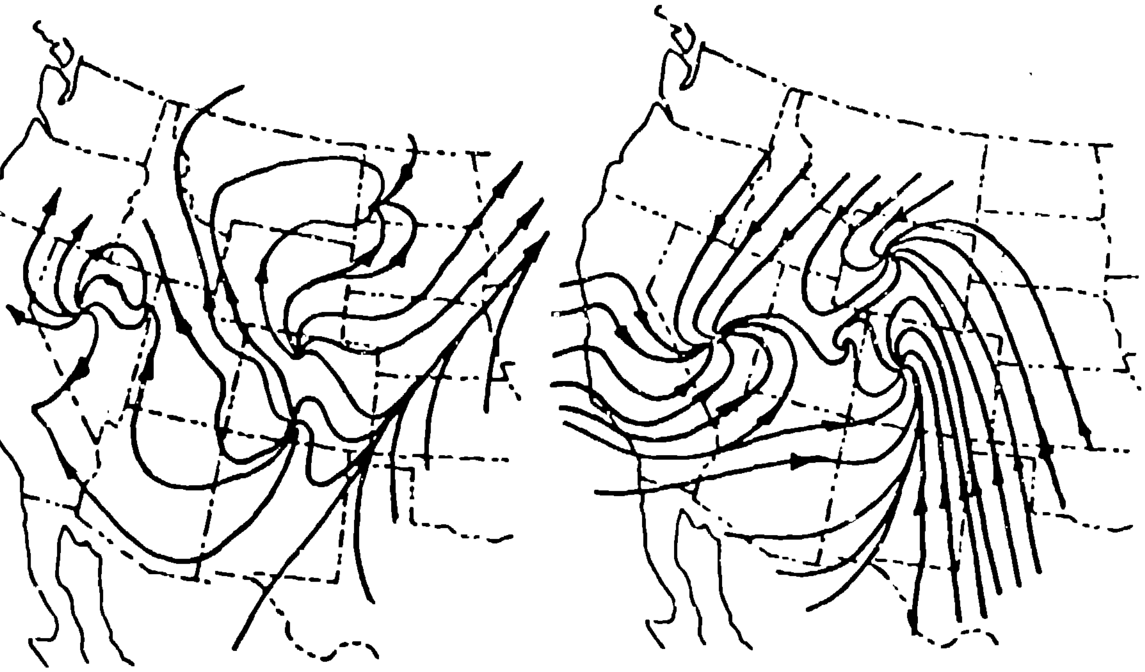

Figure 3. Estimated 850 mb wind fields at a) 0500 MST and b) 1700 MST derived from the height fields described by Reiter and Tang (1984).

barrier to the prevailing westerly winds. The vertical compression of streamlines over the ridge of the Appalachians tends to promote anticyclonic turning on the windward (western) side and cyclinic turning of the winds on the leeward (eastern) side. Warner et al (1978) show this mechanism to occur under a light westerly forcing flow with a thermal stratification typical of autumn (Fig. 4). The flow from the Kentucky-Indiana areas would be diverted significantly to the north while the Alabama-Georgia-Tennessee area emissions would divert southeastward before turning northeastward to flow up the generally polluted eastern seaboard. Michigan emissions are less influenced by the Appalachians. Under more highly stratified conditions, the northward excursions can be exaggerated since strong density (temperature) stratification suppresses the flow over the barrier and forces more flow around it. Warner et al. also calculate a diurnal effect driven by daytime heating on the Appalachian uplands. This is similar in mechanism, magnitude and depth (1-2 km) to the plateau circulation identified empirically by Reiter and Tang (1984) over the Rockies. In a related simulation not shown here, Warner et al. show the Michigan area to be influenced by land-lake breeze circulations associated with the Great Lakes.

Some valuable transport experiments have been conducted on the regional scale over the region of eastern shales. In particular, the CAPTEX program, sponsored by DOE, tracked an inert

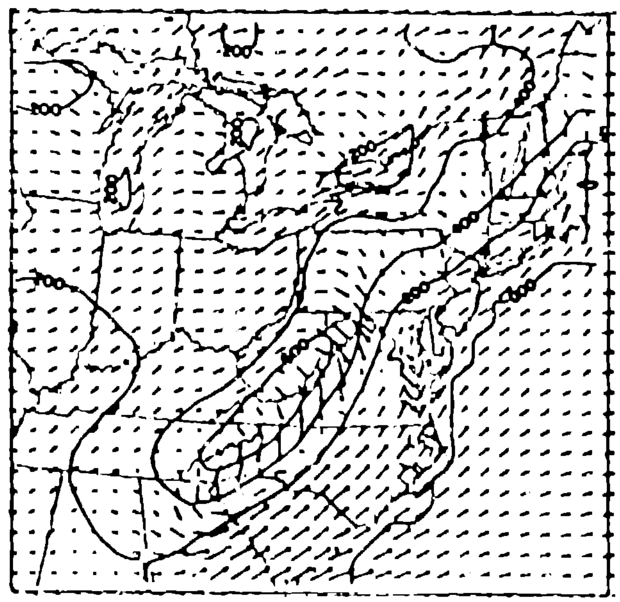

Figure 4. Wind field at 80 m above ground in a model simulation (Warner et al., 1978) with light synoptic winds. The contours are of terrain elevation plotted at 200 m increments.

tracer gas from southwestern Ohio across the mountains to the east coast under a variety of large scale meteorological conditions. Both the path of the tracer cloud and its spread was reasonably represented by model calculations that took into account both the obstacle and thermal circulation features of the Appalachians.

Local Scale Transport

Many air quality concerns center on the transport and dilution of emissions in the first ten to twenty kilometers from the facility. In view of the variety of local terrain and land use patterns it is impossible to generalize the effects introduced by lower boundary complications. For example, the confining effects of valley walls may alter the dilution and travel patterns of pollutants. There are many spectacular valleys in the Piceance Basin area of western Colorado but the western resource also includes some flat ground in the midst of broad basins. Similarly, the eastern resource area includes potential sites that range from prairie to quite rigorous mountain areas.

The mechanisms affecting winds and turbulence in valley-ridge terrains are similar to those driving the large scale circulations described above. Nighttime cooling and daytime heating on sloped surfaces creates a lateral density gradient that induces airflow down (or up) the slopes and subsequent compensation by valley axial flow that reverses from day tonight. The DOE-ASCOT program (e.g. Whiteman and Barr, 1986) has emphasized the study of these mechanisms and has yielded models that describe locally-driven valley circulations quite well. It is of considerable practical interest to distinguish well-drained valleys from those that tend to trap a pool of cool air since the latter, with their poor ventilation, will have more severe pollution episodes if there is a local source of emissions within their domain.

The lower cloudiness and generally better radiation conditions in the dry western environment has the potential of producing more vigorous local valley circulations than the east. However, these wind patterns have been observed in both areas.

Valleys influenced by more vigorous ridge top winds will exhibit channeling which tends to produce a preponderance of up- and down-valley wind situations. The meteorological community is approaching the stage where it can predict wind, temperatures, and turbulence in isolated valley-ridge terrains with little more than the topography and a general weather map as boundary conditions.

ATMOSPHERIC TRANSFORMATIONS

An active research community in atmospheric chemistry is making considerable progress toward a fundamental understanding of the reactions of organic and inorganic pollutants in a background of natural and man-made precursors. An excellent review article by Gaffney et al. (1987) emphasizes the role of natural organic emissions in the oxidation of many commonly considered pollutants. Isoprene, emitted by deciduous trees is a very reactive precursor that is expected to be much more prevalent in the eastern forests than in the west. Also, many reactions proceed at different rates in an aqueous environment than in a strictly gaseous domain. Although both regions have clouds to provide this aqueous regime, their occurrence, duration, and spatial extent in the east will be greater than in the west. Another important ingredient to the chemistry of oil shale process emissions is the solar ultra violet energy to drive photochemical reactions. This is expected to be generally greater in the high altitudes of the western shale region. Model calculations show that a clean snow-covered ground can nearly double the <u>actinic flux</u> by virtue of its high reflectance. This could favor the higher mountain locations in winter when stagnant air masses combined with vigorous photochemistry could lead to some unfavorable concentrations of secondary pollutants. The chemistry needs to be addressed on a scenario basis which should consider the organic and inorganic emissions from shale facilities, natural precursors, solar UV flux, moisture, and ventilation.

INSTITUTIONAL FACTORS

We have discussed physical and chemical differences and similarities between the eastern and western shale regions. These are useful for studying fundamentals of transport and transformation. However, the practical side of the problem is constrained by the state and federal regulations influenced in turn by proximity to population centers, wilderness areas and regulatory philosophy. One important regulation is the PSD (prevention of significant deterioration). In the west there is less industry to compete for PSD increments, but there are frequently nearby Class I areas which require no significant deterioration. The eastern shale region is more generally Classes II and III, but the oil shale industry must compete for deterioration increments. SRI International (1980) has examined the difficulty of facility siting based on many factors including atmospheric transport. All things considered, they conclude that eastern siting is more constrained than western siting. Figure 5, taken from that reference shows their estimated ease of siting based on atmospheric dispersion.

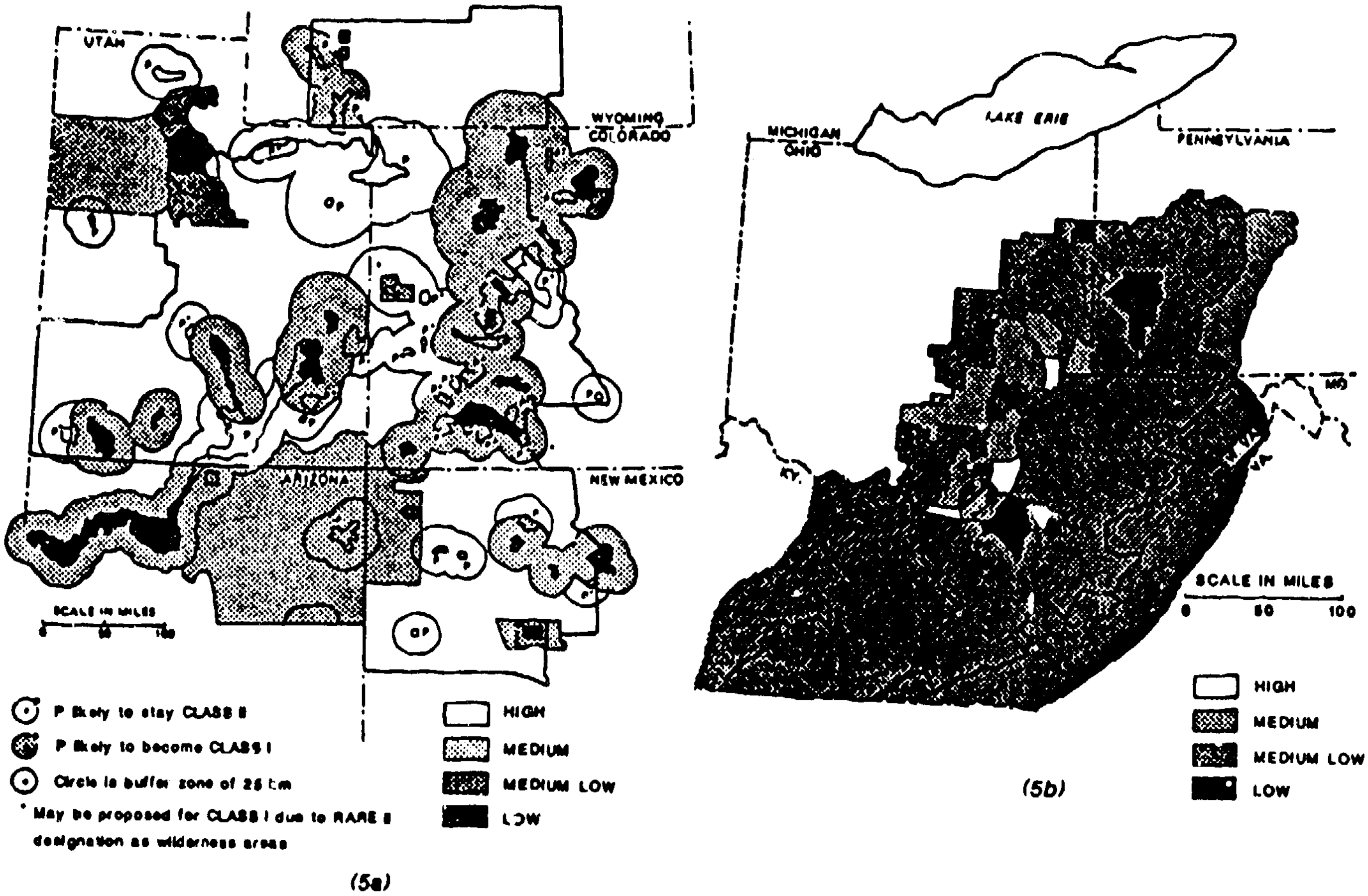

Figure 5. Relative ease of facility siting based on Air Quality.

CONCLUSIONS

We have raised more questions than we have answered in this brief summary paper, but have offered a framework for examination of the contrast of atmospheric issues associated with eastern and western oil shale development. The issues revolve around source factors, transport, chemistry, and institutional factors. The tools are just now becoming available to quantitatively address the major issues by combined modeling and experimental efforts. The industry is in a position to benefit greatly from the output of the research community so that when large scale development begins, it can proceed rationally and exploit an optimum amount of this great natural resource without seriously impacting the environment.

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